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Title: Bounding the 239Pu(n,f) cross-section

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Bounding the ^{239}Pu(n,f) cross-section

CW2017 10/4/2017

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Bounding the ^{239}Pu(n,f) cross-section:

- **Why do and should we care?**
- Classes of fission cross-section measurements
- Template of uncertainty sources
- A few examples

Fission cross-sections of actinides are important for application calculations.

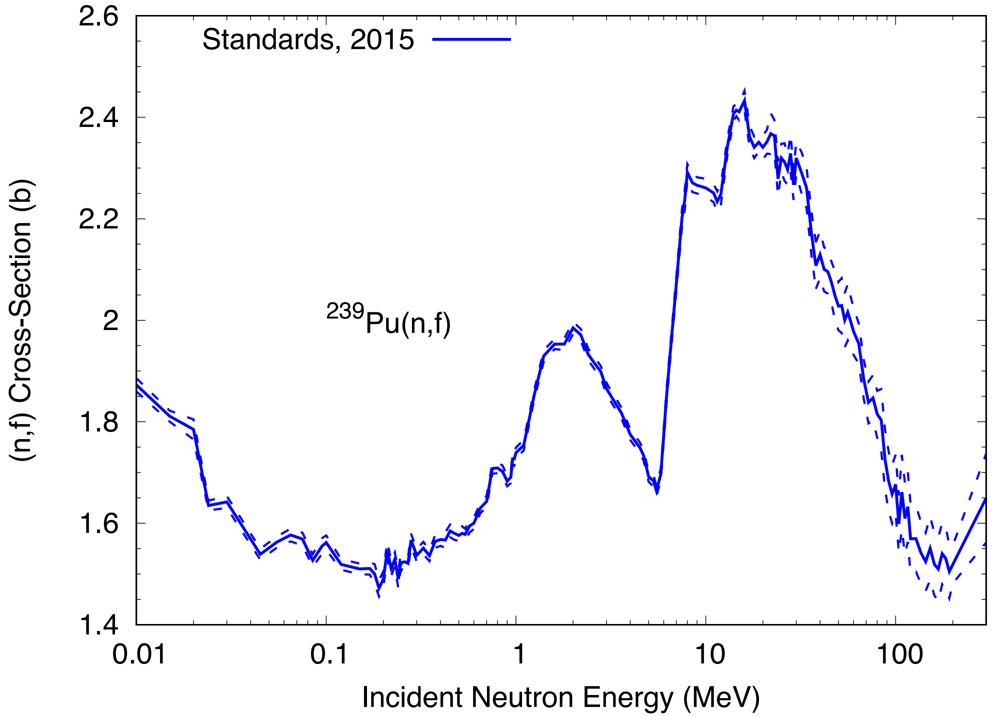
While we study here ^{239}Pu(n,f) cross-sections, the concepts can be applied to uncertainty quantification of (n,f) cross-section of many isotopes.

The (n,f) cross-sections of major actinides are important for application calculations. Uncertainties associated with these cross-sections can help us providing economical, safety and performance margins for application calculations.

In order to calculate reliable margins, we need to have *realistic nuclear data uncertainty boundaries*. *ARE OUR UNCERTAINTIES REALISTIC????*

Are the current evaluated ^{239}Pu(n,f) uncertainties realistic?

^{239}Pu(n,f) is a reference reaction evaluated as part of the neuron cross-section standards and reference project coordinated by the IAEA.



The uncertainties were considered to be unrealistically small.

It is assumed that (n,f) evaluated uncertainties are underestimated …

The uncertainties were considered to be unrealistically small. An analysis of unknown systematic uncertainties for these evaluations was included for the upcoming standards evaluation (A. Carlson et al., NDS (2018)) leading, e.g., to a correlated 1.2% systematic uncertainty on the ^{235}U(n,f).

<u>Uncertainties are assumed be underestimated because:</u>

- Unrecognized unc. across many data sets due to using the same method.
- Missing cross-correlations between experimental data.
- Missing uncertainty sources for single experimental data sets.

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- Missing uncertainty sources for single experimental data sets.

We investigate those.

Investigating missing cross-correlations between data sets and unc. for single data sets.

A. Investigate **classes of (n,f) cs measurements**, uncertainties that apply and algorithms for total covariance.

B. Extract data out of GMA and **uncertainty sources typically encountered.**

C. Template of uncertainties sources expected, **their typical size and correlations if no information is provided**.

D. Re-investigate selected GMA datasets.

Bounding the ^{239}Pu(n,f) cross-section:

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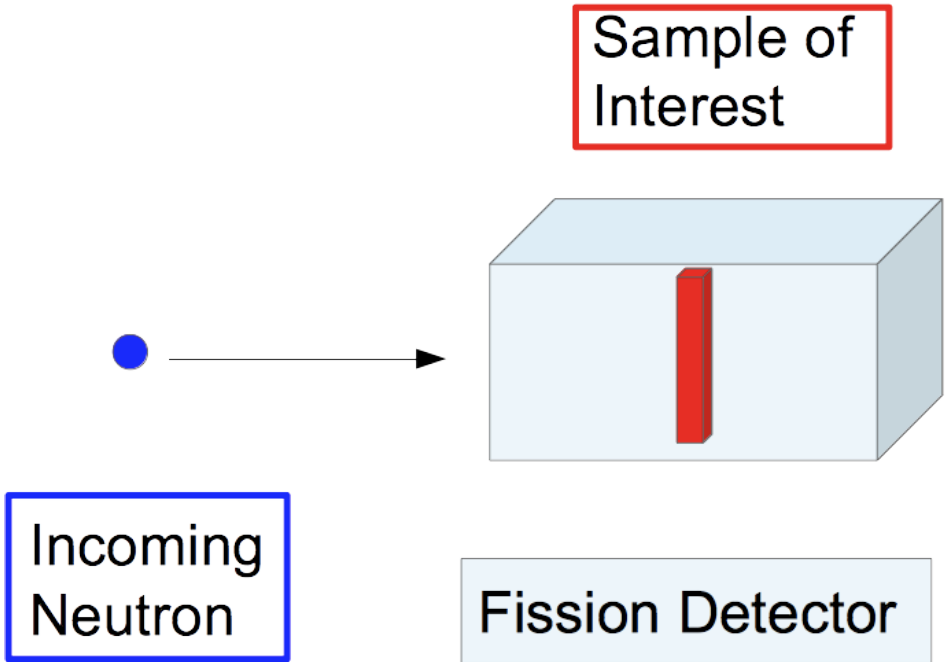
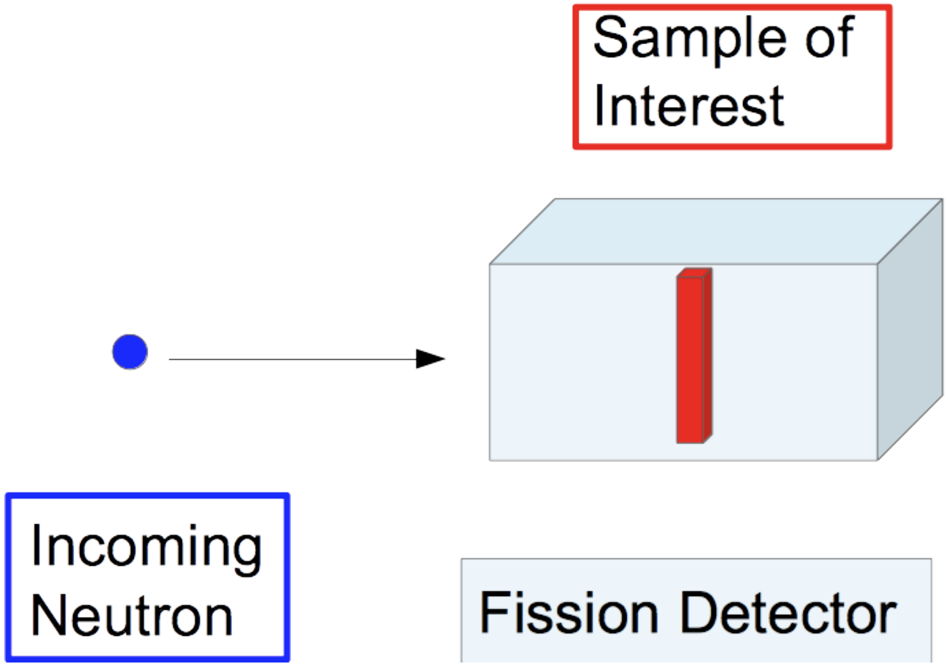
Absolute measurements: measure neutron flux, determine normalization



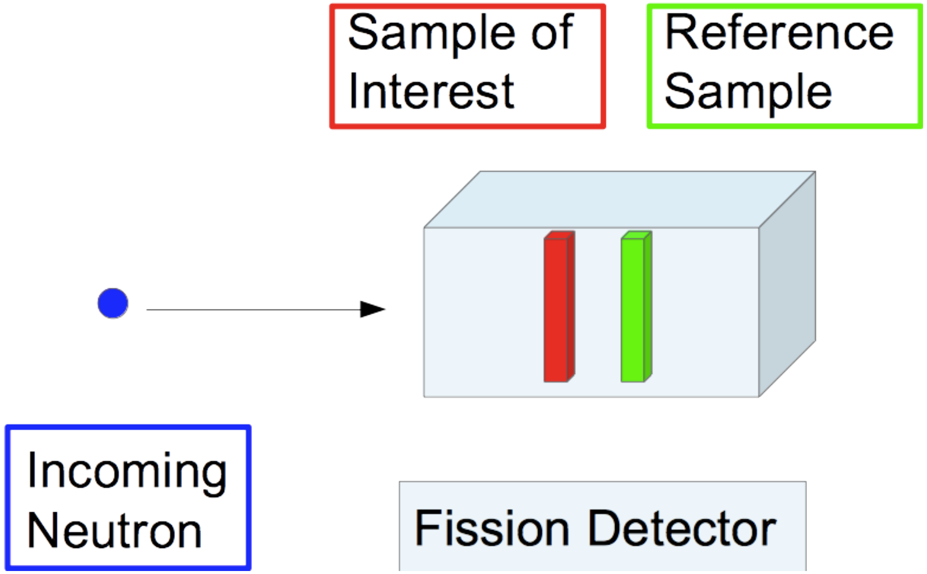
- **Neutron flux is measured**, for instance by associated particle.
- **Normalization** is given by **determining the number of atoms in the sample**.
- Detector efficiency, background, multiple scattering, attenuation, etc., have to be estimated.

Shape measurements: measure neutron flux, normalization is not defined



- **Neutron flux is measured.**
- **Normalization is not determined.** Associated unc. drop out and data are normalized during the evaluation.
- Detector efficiency, background, multiple scattering, attenuation, etc., have to be estimated.

``Clean ratio measurements": measure cs relative to another (n,f) cs with same detector

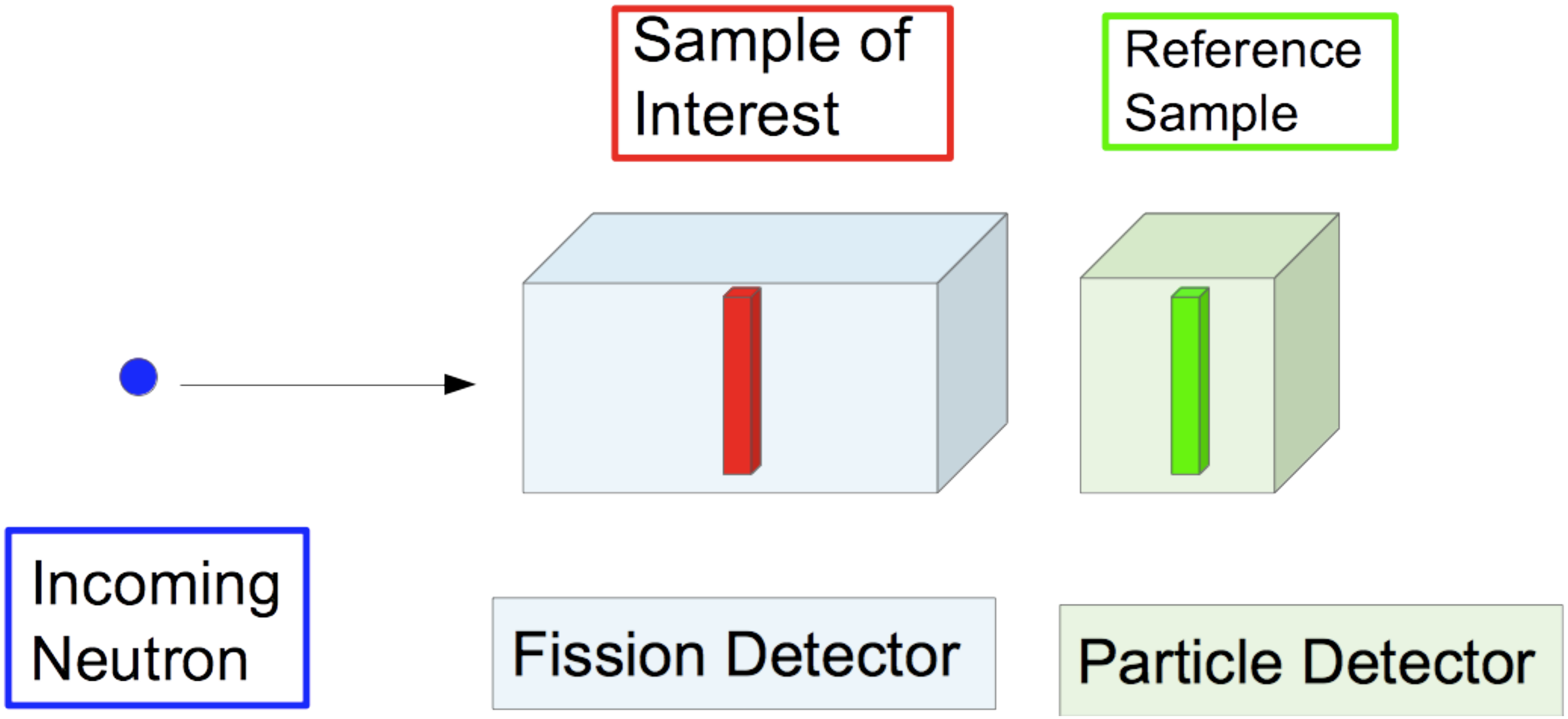


There exist absolute and shape clean ratio measurements.

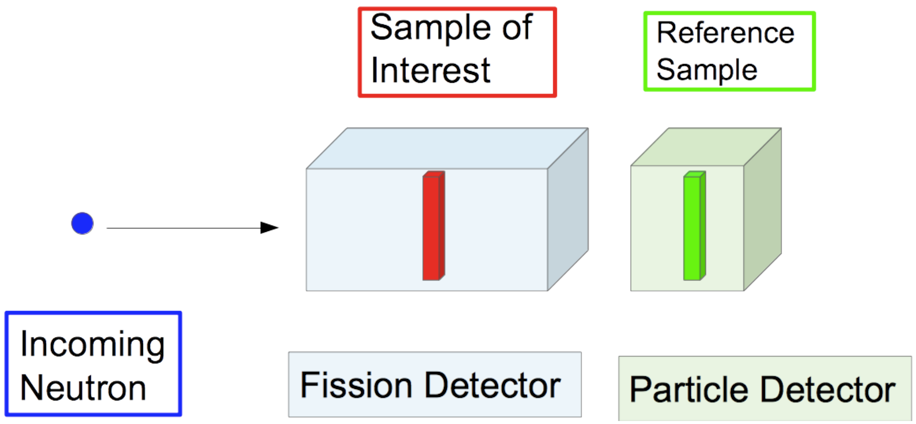
E.g., $^{239}Pu(n,f)/^{235}U(n,f)$, $^{239}Pu(n,f)/^{238}U(n,f)$

- **Neutron flux cancels.**
- **Detector efficiency might cancel or correction factor reduces.**
- Multiple scattering effects reduce.
- Attenuation effects increase.

``Indirect ratio measurements": measure cs relative to other reaction with different detector



``Indirect ratio measurements": measure cs relative to other reaction with different detector



- **Neutron flux cancels.**
- **Detector efficiency uncertainties & time resolution unc. need to be given for both detectors.**

There exist absolute and shape indirect ratio measurements.

E.g., ^{239}Pu(n,f)/^{6}Li(n,a);
^{239}Pu(n,f)/^{10}B(n,a_0)

- Multiple scattering effects reduce less than for clean ration measurements.
- Attenuation effects increase.

^{239}Pu(n,f) data sets in the GMA database underlying the standard evaluation:

Data Type	Absolute	Shape	Absolute Clean Ration	Shape Clean Ratio	Absolute Indirect Ratio	Shape Clean Ratio
Number of Data Sets	16	3	17 (16 relative to ^{235}U(n,f), 1 relative to ^{238}U(n,f)	6 (4 relative to ^{235}U(n,f), 2 relative to ^{238}U(n,f)	0	19 (17 relative to ^{10}B(n,a), 2 relative to ^{6}(Li,na)

Bounding the ^{239}Pu(n,f) cross-section:

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List of typical uncertainties and reasonable estimates for unc. and cor. if missing:

Unc. Source	Typical range	Correlations	Cor(Exp_1,Exp_2)
Sample Mass	> 1%	Full	Possible (same sample)
Counting Statistics	Sample-dependent	Diagonal	0
Attenuation	0.02-2%	Gaussian	Likely
Detector Efficiency	0-0.3%, 1-2%	Full < 10 MeV	Likely, 0.5-1.0
FF Angular Distrib.	~0.1%	Gaussian	Likely, 0.75-1.0
Background	0.2 - >10%	Gaussian	Possible
Energy Unc.	1%, 1-2 ns	Arises from conv.	Technique-dependent
Neutron Flux	0%, >1%	Full-0.5	Technique-dependent
Multiple Scattering	0.2-1%	Gaussian	0.5-0.75
Impurit. in Sample	Sample-dependent	1.0-0.9	0.5-0.75
Dead Time	>0.1%	Full	0

Comparing typical uncertainties for absolute measurements:

Unc. Source	Absolute	Clean Ratio	Indirect Ratio
Sample Mass	> 1%	Both Samples	Both samples
Counting Statistics	Sample-dependent	Both, combined	Both samples
Attenuation	0.2-2%	0.02-0.2%	0.2-2%
Detector Efficiency	1-2%	0-0.3%	1-2%, 0.5-1%
FF Angular Distrib.	~0.1%	Less than for abs.	~0.1%
Background	0.2 - >10%	0.2 - >10%	0.2 - >10%
Energy Unc.	1%, 1-2 ns	Combined	Both detectors
Neutron Flux	>1%	Cancels or small	Cancels or small
Multiple Scattering	0.2-1%	Reduced for abs.	0.2-1%
Impurit. in Sample	Sample-dependent	Both samples	Both samples
Dead Time	>0.1%	Both, combined	Both detectors

Comparing typical uncertainties for shape measurements:

Unc. Source	Shape	Clean Ratio	Indirect Ratio
Sample Mass	Not determined	Not determined	Not determined
Counting Statistics	Sample-dependent	Both, combined	Both samples
Attenuation	0.2-2%	0.02-0.2%	0.2-2%
Detector Efficiency	1-2%	0-0.3%	1-2%, 0.5-1%
FF Angular Distrib.	~0.1%	Less than for abs.	~0.1%
Background	0.2 - >10%	0.2 - >10%	0.2 - >10%
Energy Unc.	1%, 1-2 ns	Combined	Both detectors
Neutron Flux	>1%	Cancels or small	Cancels or small
Multiple Scattering	0.2-1%	Reduced for abs.	0.2-1%
Impurit. in Sample	Sample-dependent	Both samples	Both samples
Dead Time	>0.1%	Both, combined	Both detectors

Having a template of uncertainties helps pinpoint missing uncertainties:

Data Sets	611	1038	620
Uncertainty Data Types	E,CS,C	CS,C	E,CS,C
P1		1.5	1.0
P2	0.3 - 0.3	0.9 - 1.8	1.5 - 1.8
P3	0.36		0.5 - 0.70
P4	1.04	1.47	1.84 - 1.94
P5			1.0 - 1.0
P6		1.15 - 1.5	0.8 - 1.0
P7	0.3		
P8	1.01 - 1.01		2.82 - 26.3
P9			
P10		5.0	0.5 - 0.5
P11			

Data Sets	611	1038	620
ertainty Data Types	E,CS,C	CS,C	E,CS,C
P1	1.0	1.5	1.0
P2	0.3 - 0.3	0.9 - 1.8	1.5 - 1.8
P3	0.36	ok	0.5 - 0.70
P4	1.04	1.47	1.84 - 1.94
P5	ok	ok	1.0 - 1.0
P6	0.5	1.15 - 1.5	0.8 - 1.0
P7	0.3	ok	ok
P8	1.01 - 1.01	?	2.82 - 26.3
P9	?	ok	?
P10	ok	5.0	0.5 - 0.5
P11	ok	ok	ok

Having a template of uncertainties can help experimentalists in quantifying their unc.

- Templates were, e.g., developed for providing EXFOR data and uncertainties in the resonance region in F. Gunsing et al., INDC(NDS)-0647 (2013).

- Can provide guidelines **what uncertainties need to be provided for an evaluation**.

- Helps **pinpoint cross-correlations between other experiments** if the same terminology is used.

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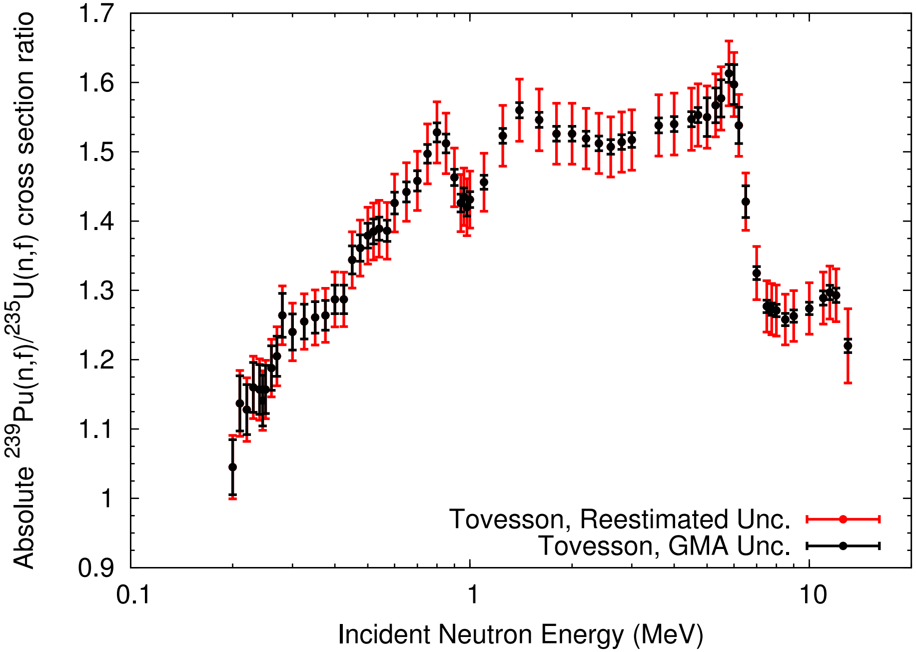
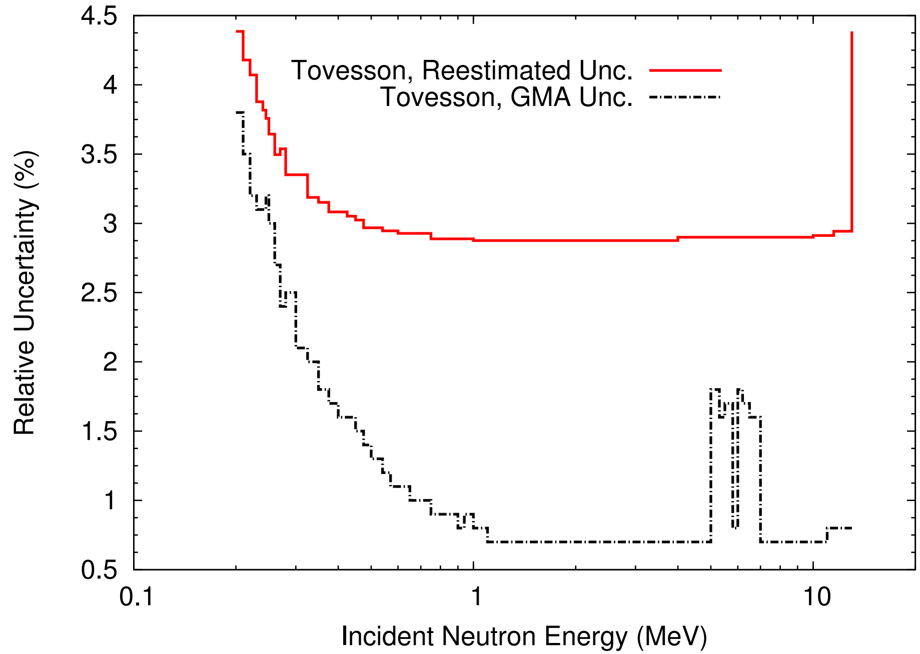
Example 1, the absolute ^{239}Pu(n,f)/^{235}U(n,f) exp. with lowest uncertainties in the GMA database:

Data Set	Data Type	Min δ	Max δ	Min E	Max E	EXFOR #
611	absolute	1.0	1.0	1.45E+01	1.45E+01	
644	absolute	2.0	2.0	1.45E+01	1.45E+01	30634
615	absolute	2.1	2.1	5.00E+00	5.00E+00	
1038	absolute	2.3	7.7	1.00E+00	5.50E+00	30670
640	absolute	2.4	3.1	1.50E-01	9.60E-01	10314
620	absolute	2.8	6.6	3.00E-02	9.80E-01	20567
⋮						
8002	ratio absolute ^{235}U(n,f)	0.7	3.8	2.00E-01	1.30E+01	14271
602	ratio absolute ^{235}U(n,f)	0.8	6.8	2.53E-08	1.00E+01	
654	ratio absolute ^{235}U(n,f)	1.0	5.7	2.40E-02	7.50E+00	
685	ratio absolute ^{235}U(n,f)	1.1	1.1	1.45E+01	1.45E+01	
653	ratio absolute ^{235}U(n,f)	1.2	6.9	1.20E-01	7.00E+00	40824
1014	ratio absolute ^{235}U(n,f)	1.3	1.6	8.50E-01	6.00E+01	13801
600	ratio absolute ^{235}U(n,f)	1.7	27.4	8.50E-04	3.00E+01	10562
605	ratio absolute ^{235}U(n,f)	1.7	15.3	5.50E-03	1.00E+00	20363
608	ratio absolute ^{235}U(n,f)	2.0	12.6	4.50E-02	5.00E-01	21463
609	ratio absolute ^{235}U(n,f)	2.0	2.1	1.00E+00	1.40E+01	21195
631	ratio absolute ^{235}U(n,f)	2.1	2.1	2.53E-08	1.50E-01	
1012	ratio absolute ^{235}U(n,f)	2.1	5.8	5.70E-01	2.00E+02	41455
⋮						
630	ratio shape ^{10}B(n,α)	2.3	5.0	2.53E-08	1.50E-01	

Sample mass unc. should be 1% questionably small!!!

A normalization uncertainty was overlooked for Tovesson et al. ^{239}Pu(n,f)/^{235}U(n,f)





Example 2, the absolute ^{239}Pu(n,f) exp. with lowest uncertainties in the GMA database:

This measurement is part of a series and correlated with 615-617.

Also, sample mass unc. Should be 1%, questionably small.

Data Set	Data Type	Min δ	Max δ	Min E	Max E	EXFOR #
611	absolute	1.0	1.0	1.45E+01	1.45E+01	
644	absolute	2.0	2.0	1.45E+01	1.45E+01	30634
615	absolute	2.1	2.1	5.00E+00	5.00E+00	
1038	absolute	2.3	7.7	1.00E+00	5.50E+00	30670
640	absolute	2.4	3.1	1.50E-01	9.60E-01	10314
620	absolute	2.8	6.6	3.00E-02	9.80E-01	20567
		⋮				
8002	ratio absolute ^{235}U(n,f)	0.7	3.8	2.00E-01	1.30E+01	14271
602	ratio absolute ^{235}U(n,f)	0.8	6.8	2.53E-08	1.00E+01	
654	ratio absolute ^{235}U(n,f)	1.0	5.7	2.40E-02	7.50E+00	
685	ratio absolute ^{235}U(n,f)	1.1	1.1	1.45E+01	1.45E+01	
653	ratio absolute ^{235}U(n,f)	1.2	6.9	1.20E-01	7.00E+00	40824
1014	ratio absolute ^{235}U(n,f)	1.3	1.6	8.50E-01	6.00E+01	13801
600	ratio absolute ^{235}U(n,f)	1.7	27.4	8.50E-04	3.00E+01	10562
605	ratio absolute ^{235}U(n,f)	1.7	15.3	5.50E-03	1.00E+00	20363
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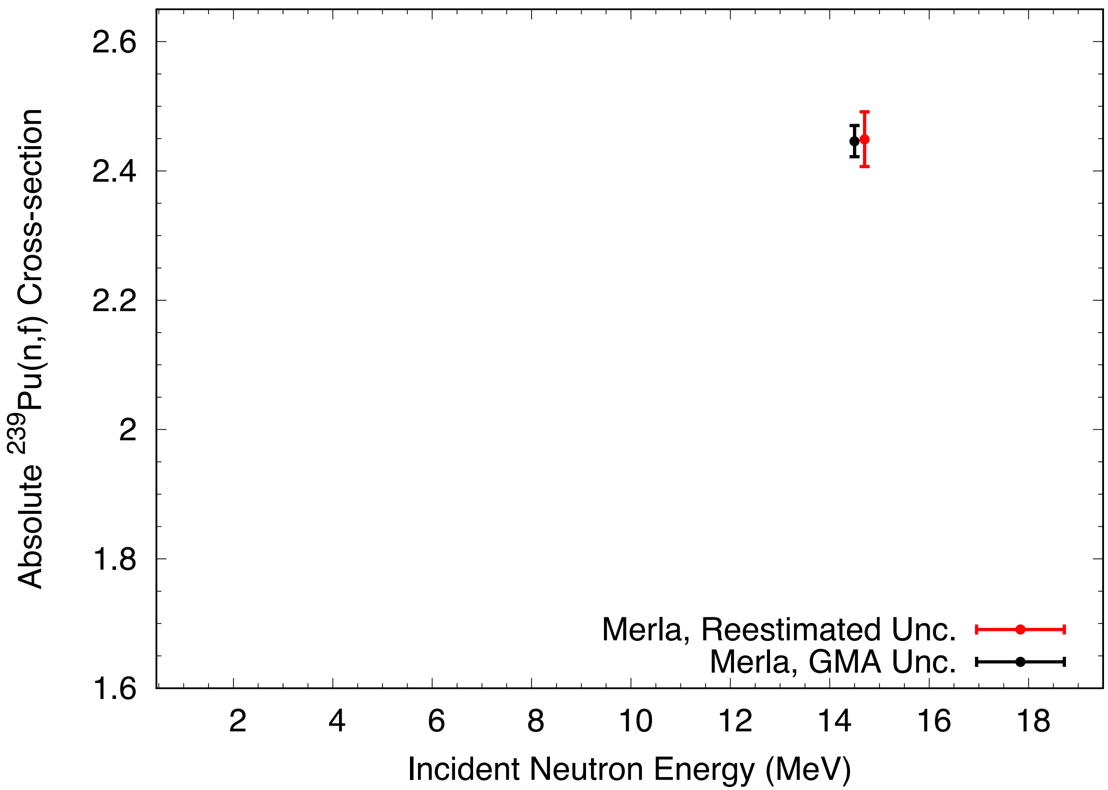
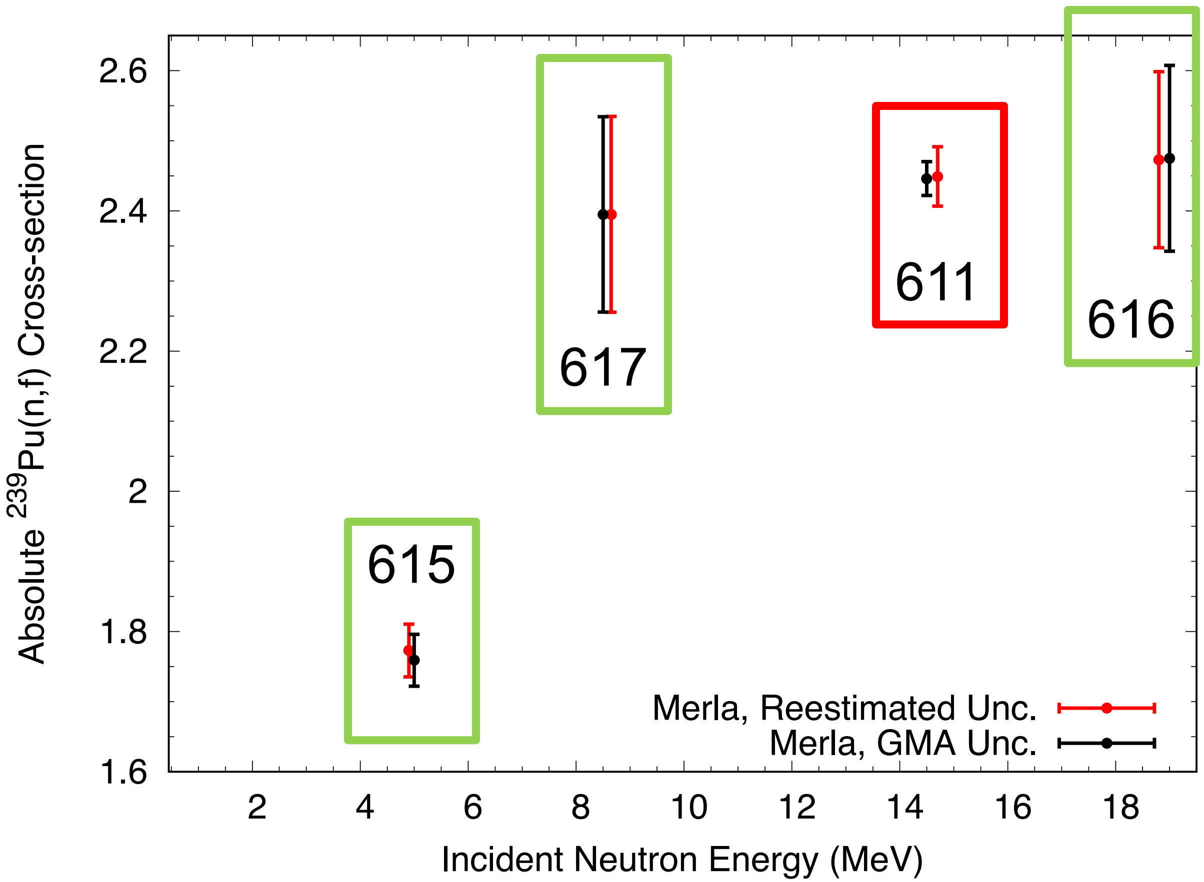


GMA unc.: 1%

Reestimated unc.: ***1.7%***

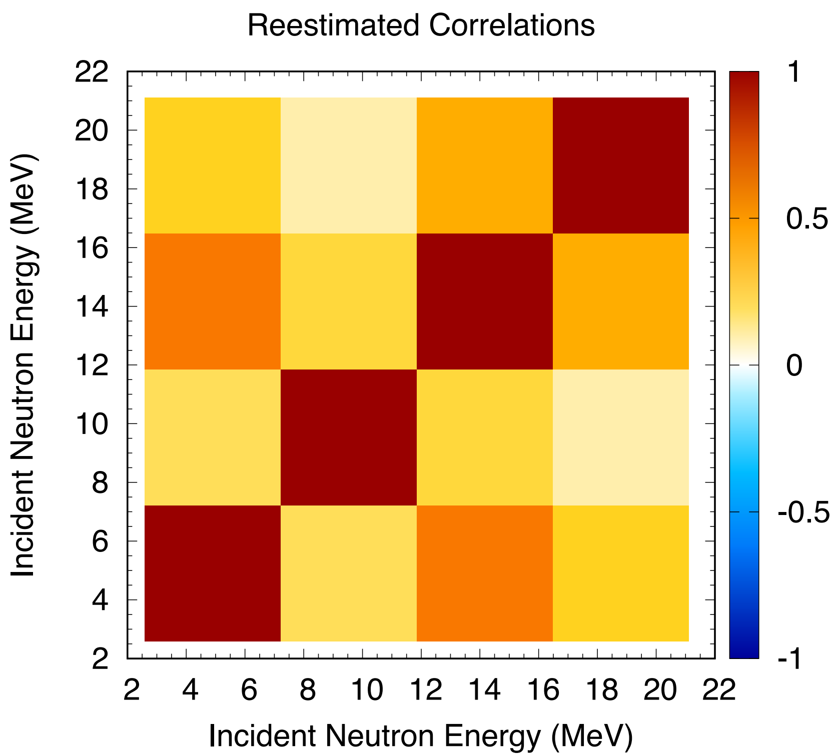
Sample mass unc. of 1% missing and background unc. of 0.5% missing.

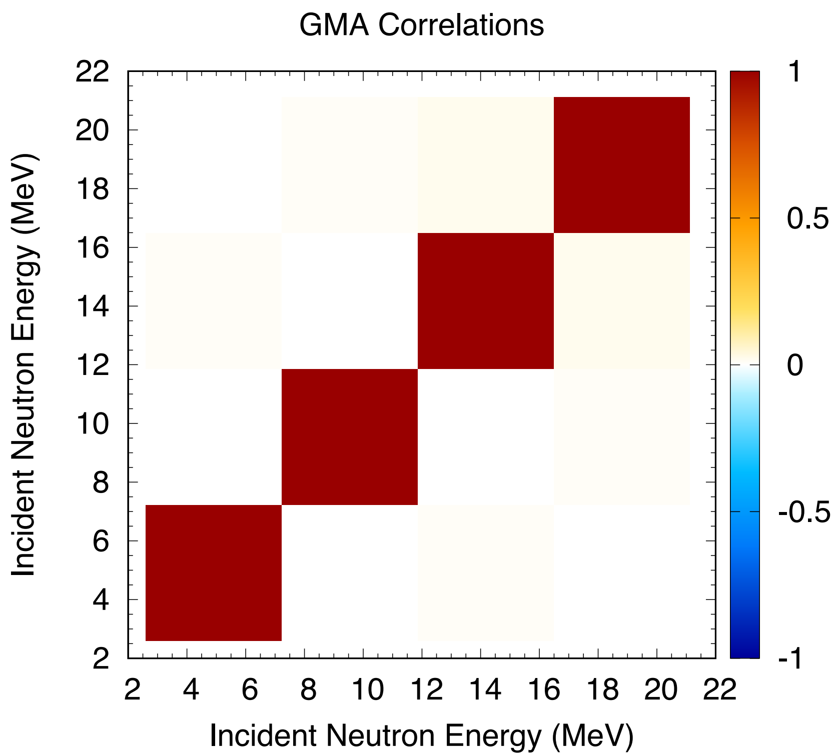
Example 3, correlations between experimental data sets of Merla because part of a series:



Cross-correlations arise because same sample was used, same detector, same multiple scattering correction, etc.

Example 3, correlations of Merla series differ between GMA and ARIADNE estimate:





Summary and outlook:

- **A template for typical (n,f) cross-section uncertainty sources encountered in absolute, shape, clean and indirect ratio measurement was established including ranges of uncertainties and suggestions for correlation matrices if information is missing.**

- **Algorithms developed were implemented in ARIADNE** and a few representative examples were shown where the comparison of GMA total unc. with the template highlighted questionable data in GMA.

- To-Do: investigate whether uncertainties and cross-correlations are missing for all ^{239}Pu(n,f) data sets in GMA and re-evaluate with updated covariances.

Thank you for your attention! **Questions?**